Facilities for scramjet improvement

Krasilnikov A.V.,Kozlovsky V.A., Lapygin V.I., Michailov A.V.

Central Research Institute of Machine-Building (TSNIIMASH),
Korolev, Moscow Region, Russia

The description of TSNIIMASH facilities for improvement of scramjet inlets and combustion chambers is presented. For research of inlets it is offered to use a large-scale hypersonic wind tunnel U - 306-3, working at Mach numbers 2, 3, 4, 6, 8, 10 with a nozzle-exit diameter of 1,2 m. The description of this facility activity scheme and its basic distinctive parameters are given. It is marked, that the facility Y - 306-3 can be used to test large-scale models and model flying velocities and dynamic head for different altitudes. For analysis of hydrogen - air or hydrocarbon - air mixtures supersonic combustion in scramjet combustion chambers is offered to use a special test-bed on the basis of facility U – 12 modernization. The test-bed includes the pressure vessel of a variable volume, succeeded hypersonic nozzles on Mach numbers 4, 6, 8, 10, combustion chamber, exit nozzle and exhaust system. The maximal pressure in the pressure vessel can reach 50 MPa. The combustion chamber has the cylindrical shape with an interior diameter of 0.5 m and length of 9 m. It allows to test real injection systems during tests. The system of an exhaust includes a gas holder with diameter of 3.2 m and volume of 180 m^3. She also is equipped with potent vacuum pumps, which one can create rarefaction ~ 1 Pa for rather short time. The problems of scramjet creation are analyzed, which one can be resolved on the facilities.

A possibility of the scramjet using for hypersonic flight vehicles (HFV) with large value of lift-to-drag ratio now is widely studied [1÷ 8]. It is conditioned, mainly, by advantage of such engines as contrasted to by other in view of high values of specific impulse - thrust force, coming per unit of propellant consumption, and usage as an oxidant of atmospheric air.

The problem of scramjet creation can conditionally be sectioned into two main bodies: development of the high-performance inlet and supersonic combustion chamber. The both problems are rather difficult . Realization of fundamental experimental researches and, first of all, in ground conditions therefore is necessary.

For an experimental research of the inlet it is possible to use already existing wind tunnels working in range of Mach numbers $M_\infty = 4 \div 10$. In particular for this purpose well approaches, for example, the TSNIIMASH hypersonic facility U - 306-3 [9], which one works in this range of

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Mach numbers, has nozzles exit section diameter of 1.2 m, and length and diameter of a working section, accordingly 6 and 2.5 m (see scheme in a Fig. 1).

In this facility it is possible to test full-scale parts of inlets or their large-scale models. A distinctive feature of the facility is the change in a broad band of Reynolds numbers $Re_\infty = (0.5 \div 200) \cdot 10^6$, counted on the reference size of 1 m, that allows to model an altitude of flight (Fig. 2). It is reached at the expense of a capability of working gas exhaust in atmosphere or turbo exhaust station (TES) of high power, up to 100 MW.

A gas supply of the facility realizes from cylinder with an operating pressure 20 MPa. For organization in a working section of flow reshaped nozzles with Mach numbers $M_\infty = 6$, 8 and 10, the unit from 10 high-performance heaters of continuous operating with general power 75 MW is established. Such design provides a heating of a working flow in a broad band of the consumptions (from 15 kg/sec up to 120 kg/sec) and temperatures (from 493 K up to 1073 K).

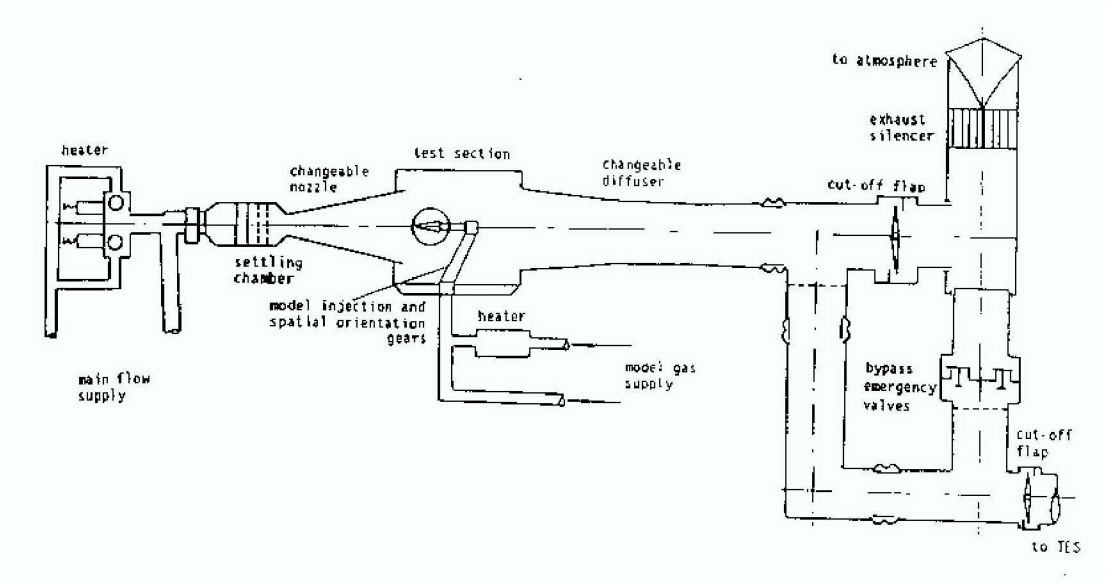

Fig.1. The wind tunnel U-306-3 scheme

The facility U - 306-3 is supplied by a mechanization system, which one allows to change a model angle of attack in range 15 ÷ 20°, angle of slide - ± 15°, longitudinal and vertical displacement, accordingly, 0 ÷ 670 mm and 0 ÷ 300 mm, angular travel with speed 20 deg/sec and linear moving with speed of 10 mm/sec. The facility measures system includes nominal measurements of flow parameters, pressure, temperature and heat flows on models. The cylindrical working section is made by the way Eifelle chambers, has flat lateral walls, on which one is mobile the panels with optical glasses of 800 mm diameter are established.

The intake of different gases (including heated) inside of models allows to use the facility for research of HFV models with running engines, that is necessary for improvement of the integrated schemes.

The experimental HFV models, intended for flight tests, for example, X-43C [10], can be previously tested in the facility U - 306 -3 for research of scramjet start at different Mach numbers and static pressures as if on a flight altitude.

For a carrying out of tests with models of an oversize in a contour of a wind tunnel the application of changeable aerodynamic diffusers with relative diameters (in relation to a width of nozzle) 1, 1.5, 1.75 is possible.

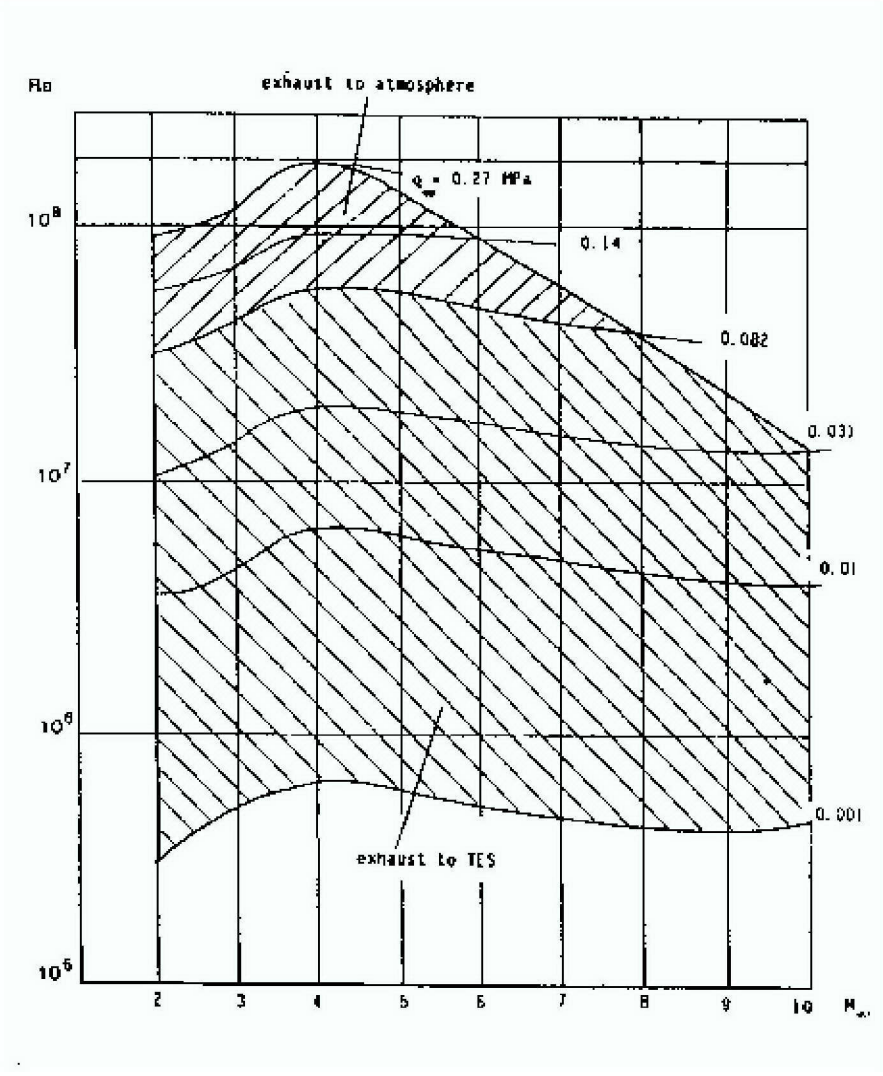

Fig.2. Reynolds numbers and dynamic heads at the facility U-306-3

The activity of the hypersonic inlet in the flight will realize at different Mach numbers. For minimum gas dynamic losses guarantee the geometry of the inlet (angle of wedges leans, position of a shell and the throats) should also change with a Mach number. The creation of a variable-geometry inlet is a composite technical problem. To the present time two control modes -

mechanical (change of inlet geometry) and MHD control in a channel [11-13] are proposed. In both cases the realization of a large volume of experimental researches in a wind tunnel is necessary.

For analysis of supersonic mixtures combustion of hydrogen - air or hydrocarbon - air in scramjet combustion chambers is proposed to use a special test-bed on the basis of facility U – 12 modernization. The scheme of such bench is shown in a Fig. 3.

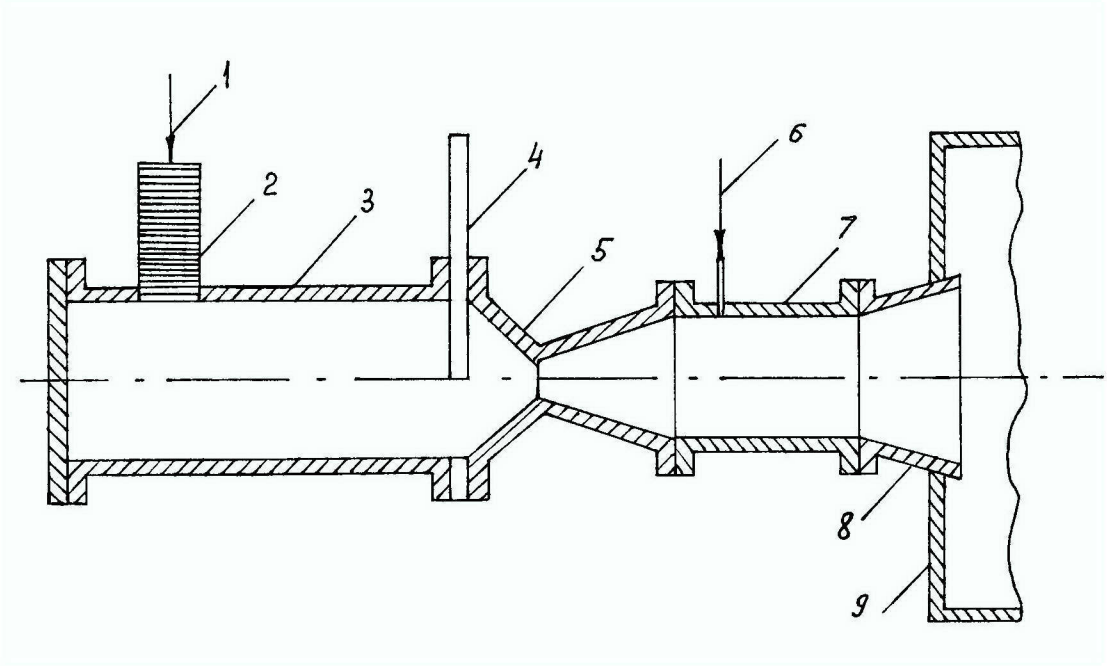

Fig. 3. A bench for an experimental research of supersonic combustion of different mixtures in air medium.

Air (1) goes in the high pressure vessel (3) through an ohmic or electric arc heater (2). The high pressure vessel can consist of one or several identical compartments shaped of the barrel with a inner diameter of 0.5 meters, length of 9 meters, by a volume of ~ 1.6 m^3 and can maintain pressure up to 50 MPa. After discovering a gate valve (4) heated high-pressure air goes in a changeable Laval nozzle (5). It is supposed to use changeable nozzles counted for Mach numbers 4, 6, 8 and 10. The supersonic airflow at such Mach numbers goes in the combustion chamber (7). In this moment in the combustion chamber the fuel injection (6) implements also. As fuel is possible application of hydrogen or different hydrocarbon. To set fire to a combustion-mixture (if its temperature is lower than burning point) one can use different systems, including spark and plasma. As the combustion chamber it is possible to use off-the shelf compartments as well as for the high pressure vessel (7), with the same geometrical parameters.

In the Table 1 the parameters of supersonic air modes, possible for implementation on a bench are presented at Laval nozzles usage with exit section diameter of 500 mm.

Table 1

M_∞	d_{crit} mm	F_{crit} cm^2	P_0 atm	T_0 K	G Kg/s	m kg	t s	p_∞ atm
4	152.72	183.18	10	300	50.6	263	5.2	0.0660
6	68.56	36.92	50	500	36.5	112	3.06	0.0316
8	36.26	10.33	100	800	15.7	67	4.26	0.01024
10	21.60	3.66	200	1300	9.0	105.2	11.67	0.00470

In the Table 1 are presented: the Mach numbers M_∞, nozzles diameter and throat section area (d_{crit} and F_{crit}), stagnation pressure and temperature (P_0, T_0), mass flow and initial weight of air (G, m), time of the expiration t and static pressure on nozzle exit p_∞.

From the Table follows, what for initial air weight accommodation at given parameters it is necessary to use as the high pressure vessel at M_∞= 4 above of ten compartments with a volume V = 1.6 м3, at M_∞= 6 two compartments, and for M_∞= 8 and 10 it is enough one only.

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